THE CRYOGENIC SYSTEM FOR THE MTL MAGNET TEST STANDS*

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Abstract

This paper briefly describes the cryogenic Test capabilities of the Magnet Test Laboratory (MTL). The instrumentation for controlling the operating condition of the magnet cryogenic test and for verifying the requirements of the SSC magnet performance is introduced. The development of the thermometer system, particularly the He vapor preasure thermometers with differential pressure transducer,is presented in detail The 10-kA vapor-cooled power leads were optimized thermally, with consideration for the different fin shapes, diameter, lengths, and RRRs of the power lead material. Two mechanical designs are introduced. The anti-cryostats, so-called warm bore and warm finger, that provide a warm environment to allow the magnetic field-measuring probe run through the 4.2-K beam tube are described. The warm finger for SSC short-magnet cryogenic tests was manufactured and successfully used. Finally, the feed and end cans---used to provide cryogens to the magnet being tested as well as cryogenic vacuum---and the support of other instrumentation are described.

INTRODUCTION

About 11,000 superconducting magnets of various types, including dipoles, quadrupoles, and specialty magnets, will be produced by magnet subcontractors and by the SSCL itself for use in the SSC accelerator, [1] The MTL will be used to test a considerable portion of the total magnet production in order to control the manufacturing process and to verify the requirements of the magnet performance. With ten cryogenic test stands, MTL is capable of housing tests for 30 dipoles and 5 quadrupoles per month. For developmental purposes of the SSC magnets, there will be two R&D test stands, designed to accommodate heavily-instrumented magnets. There will also be one test stand capable of testing a three-magnet string. In order to accomplish the test tasks, a comprehensive cryogenic system, including refrigerator, cryogenic instrumentation, vapor-cooled power leads, anti-cryostats, feed and end cans, and other associated systems, has been or is being procured, designed, developed, and tested. This paper will briefly discuss the progress to date.

CRYOGENIC TEST CAPABILITIES

Figure 1 is the general cryogenic test flow schematic at the SSC MTL. He is transfered from the refrigerator by a pumping box through the sub-colers in the distribution boxes, then into the feed cans. In order to bettr control the He temperature to the magnet, there is a temperature-controlled heater located in the He transfer line between each distribution box and feed can. The He from the feed can first flows through the single phase return line, by-passing the magnet to the end can, then turns around to cool the magnet cold mass. This flow arrangement avoids the influence of heat leaks on the magnet cold mass due to a heat leak through the vapor-cooled power leads.

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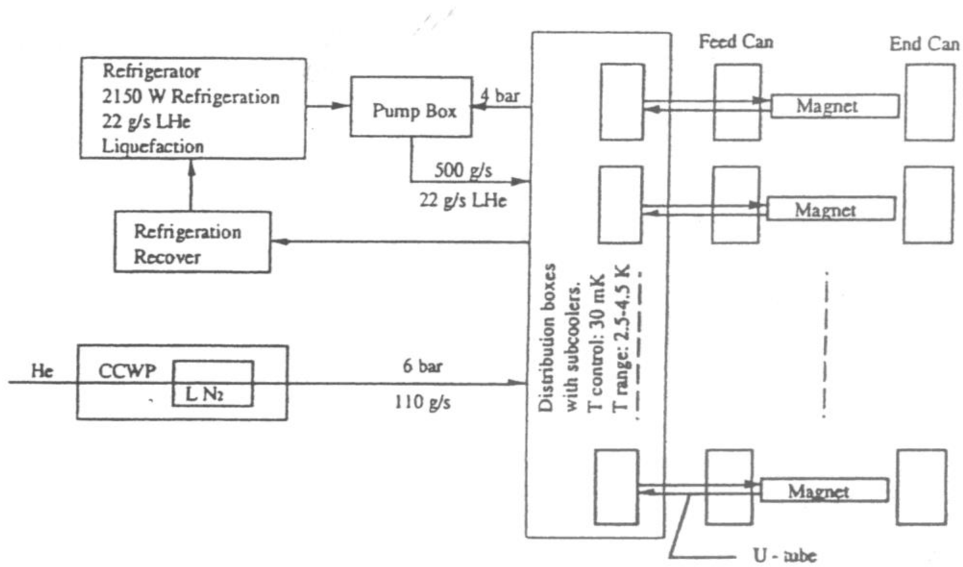

Figure 1. Cryogen flow schematic of the magnet test at MTL.

The cryogenic test system capabilities at MTL are briefly summarized as follows:

1. There will be a total of 2150 W of refrigeration power at 4.2 K plus 22 g/s LHe.
2. Total single-phase mass flow rate will be maximum 650 g/s.
3. The clean, cooldown, warm-up and purge (CCWP) system flow rate is 110 g/s.
4. The lowest temperature of the system is 2.5 K
5. The MTL is able to cold-test 7 magnets simultaneously at 4.5 K and 100 g/s. The cryogenic test stands are configured as follows:

8 production magnets (dipole length 15.5 m, quadrupole length 5 m)
2 R& D magnets
A three-magnet string
Several short magnet vertical test dewars.

INSTRUMENTATION DEVELOPMENT

General Introduction

In order to control the operating condition of magnet cryogenic tests and to verify the requirements of the magnet performance, a large number of instruments[2] will be allocated and installed inside the feed and end cans of the test stand. This instrumentation includes the temperature sensor system, cold and warm pressure transducers, cryogenic mass flow meter groups, and the wiring systems for wiring all of the sensors out to reach the data acquisition. Besides the instrumentation, installed in the cans of the test stand, there is additional instrumentation placed in the magnet itself: strain gauges, strip and spot heaters, and the voltage taps for quench detection. Figure 2 is the simplified block schemntic of the sensor distribution.

Design of The Thermometer System

Thermometer Accuracy Requirements. According to the heat leak budget of the SSC magnet, the temperature rise of the cryogens was calculated between both ends of the cold mass, and the temperture change of cryogens was noted along the magnet 20-K shield and along the 80-K shield as functions of cryogenic flow rates and static heat leaks, respectively. The results were in detail in a separate paper.[3] The choice of the temperature accuracy rcquirement for the SSC magnet test is based on the quench test results as well as the potential high-accuracy heat leak measurement. Temperature accuracy requirements for magnet testing are most important in the temperature region of 2-10 K. The thermometer accuracy requirements in MTL are given in Table 1.

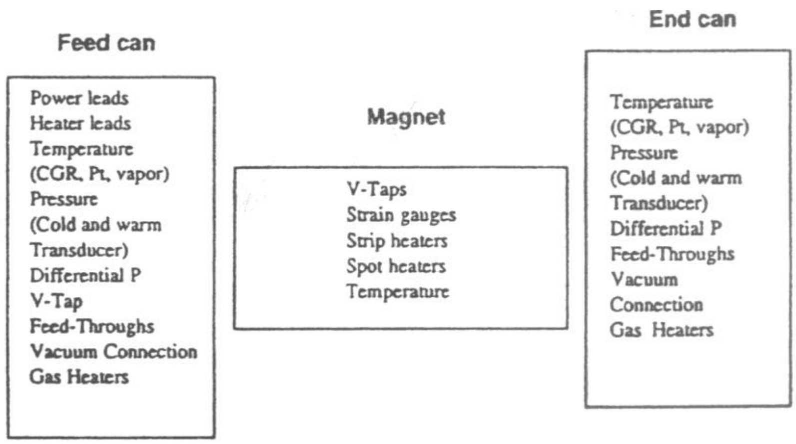

Figure 2. The instrumentation distribution of the SSC magnet cryogenic test stand at MTL.

Table 1. MTL Thermometer Accuracy Requirements.

Cryogen	Type	Mounting	T Range	Relative Accuracy
He	CGR	In stream	2.4-10K	± 2 mK
	CGR	In stream	10-20K	± 10 mK
	CGR	In stream	20-40K	± 50 mK
	Pt	In stream	40-80K	± 50 mK
	Pt	In stream	80-300K	± 500 mK
N_2	Pt	In stream	80-300K	± 50 mK

According to the accuracy requirements, three types of thermometer packages were developed for the MTL cryogenic tests: package #1 for He line (2.5 K-300 K) 2 carbon glass, 2 platinum; package#2 for N_2 line (77 K-300 K), 2 Platinum; package # 3 for He line (single-phase He), 4 vapor pressure thermometers (the VPT package).

The Design of VPT System. The VPT has a higher accuracy than resistance thermometers, particularly in measuring the temperature differences between two locations by using a VPT group. In addition, VPT is also better to measure an average temperature than are resistance thermometers. The VPTs at MTL will be located across the magnets and connected to pressure transducers, as shown in Figure 3. To reduce the heat transfer to the VPT bulb the capillary tubing should be thermally stationed to the 80-K shield and also to the He piping. The VPT mounting detail is shown in Figure 4. The heat leak to the bulb at 4 K from the single phase piping will be 5 μW and 1.2 mW from 80 K to the single phase, when stainless tube with 3.18-mm o.d. and 1.24-mm thickness is used. The volume of thc bulb is 0.3 cm^3, and the volume of warm system connected to each tube is 70 cm^3. When the system is charged to 52 psi, the VPT can he operated from 3.5 K with 80% of LHe in the bulb to 5 K with 17% LHe in the bulb. With a Sensotec Super TJE absolute pressure transducer (50 psi range, 0.05% F.S. accuracy), the T accuracy will be ± 2.5 mK at 3.5 K and ± 1.1 mK at 5 K. If the temperature differences across the magnet or between the upper and lower nozzle are to be measured, the Sensotec Z differential pressure transducer (2 psi range, 0.25% F. S. accuracy) will measure $\triangle T = 150$ mK with an accuracy of ± 0.5 mK.

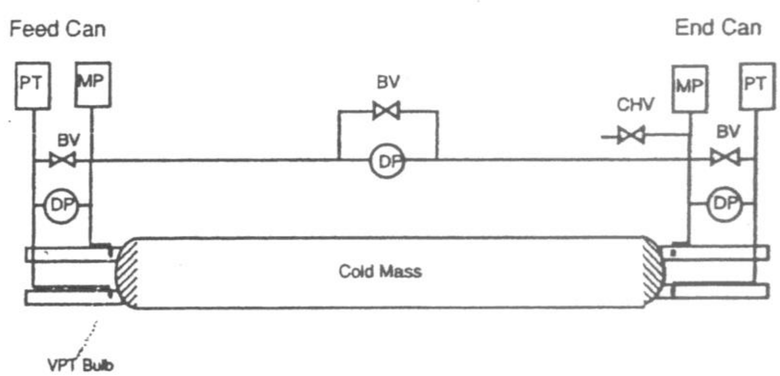

Figure 3. The Schematic of the VPT system with the differential pressure transducers,used for precise temperature

measurement:DP-Differential Pressure Transducer,BV-Bypass Valve;MP-Mechanical Pressure Transducer;PT-Pressure Transducer,CHV-Charge Valve.

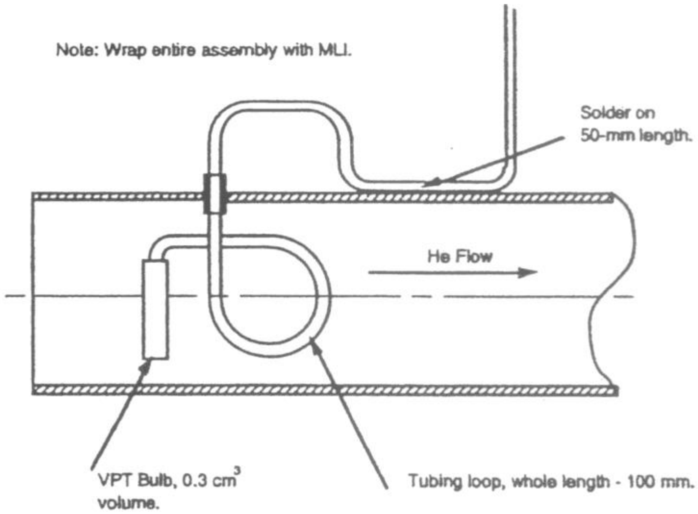

Figure 4. The VPT mounting assembly.

THE DESIGN AND THERMAL OPTIMUM ANALYSES OF 10 KA VAPOR COOLED POWER LEADS FOR MTL

The optimal thermal design is required for the He vapor-cooled power leads that will supply 10 kA to superconducting magnets in the MTL. A survey of existing designs showed that there are different approaches to designing vapor-cooled power leads as well as different objectives in determining the optimum. A design method was followed that meets the requirements for vapor-cooled power leads to be used at the SSC.

The diameter which minimizes the Carnot work for a given lead length has been determined for a spiral-fin, 10-kA power lead design for several different lengths, two different fin geometries, and two levels of RRR.[3] The acceptable lead dimensions for a prescribed set of cryogenic system refrigeration and liquefaction load budgets have also been calculated.[3] In general, the constraints permit the use of the optimum design length and diameter. This note provides direction for a power lead designer in the selection of these important dimensions.

A summary of the acceptable lead dimensions for a heat transfer constraint of 7.9 W to the 4 K level and He mass flow of 0.5 g/s is illustrated in Figure 5. The acceptable diameters shall be smaller than the heat transfer constraint and larger than the mass flow constraint. The BNL design, with L=46 cm and D=1.4 cra, falls slightly above the optimum when RRR=100, and above the mass flow constraint when RRR=40. The Fermilab design with L=130 cm and D=2.54 cm is outside the range of computed data. Even so, it appears that it, too, is within the acceptable design space determined with this model.

For the MTL a 10-kA lead is being designed, as shown in Figure 6, based on the analysis. The main difference between design A and design B is that the electric insulation assembly, which isolates the ground potential parts of the lead from the high power parts, was moved into a warmer region in design B from design A. Therefore, design B has an advantage over design A in that it prevents vacuum and He leakage in the o-ring seals due to low temperature. The preliminary selection of the length and core diameter are 120 cm and 2.2 cm, respectively. For the MTL 10-kA lead, the fins will be soldered to the core.

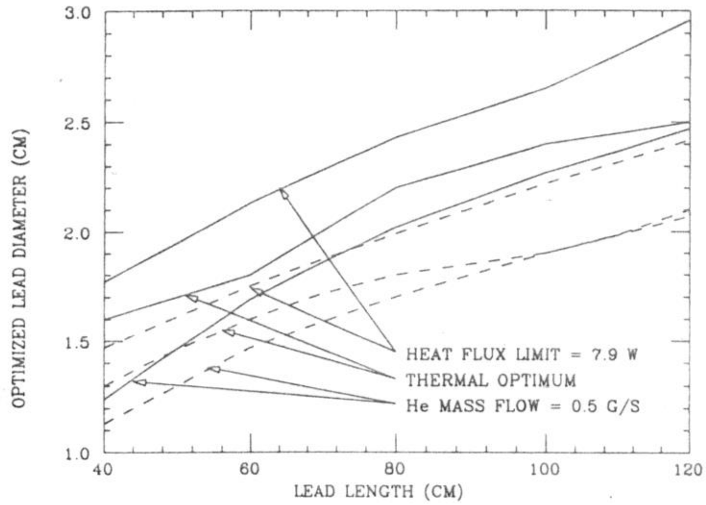

Figure 5. The computing simulations of the optimum thermal design of 10-kA vapor-cooled leads as functions of diameters, lengths, fin shapes, and RRRs for MTL(___-RRR=40; ----- - RRR=100).

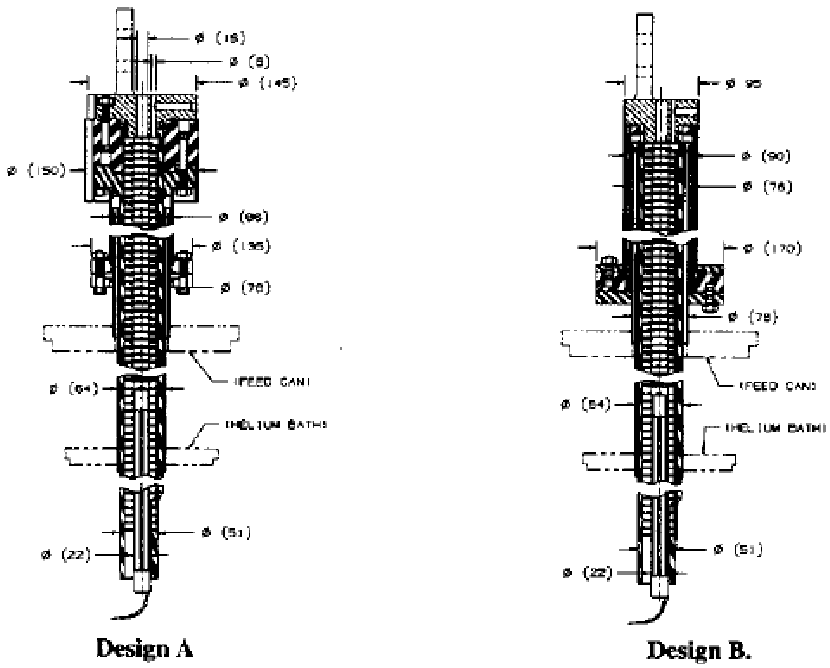

Figure 6. The two mechanical designs of a 10 kA vapor cooled power leads.

In order to accommodate this, a slight modification to the fin dimensions is necessary. The fin length will remain the same, but the thickness and spacing tentatively are 0.127 cm and 0.381 cm, respectively. It is observed from these simulations that there is little difference in the lead performance for this magnitude of change in the fin geometry. The authors will introduce more details of the design and analyses in a separate paper.

ANTI-CRYOSTATS (WARM BORE AND FINGER) DESIGN

It is necessary to design anti-cryostats, so-called warm bore and war finger, for the purpose of making magnetic field measurements during magnet cryogenic tests. The warm bore inserts into the magnet beam tube, which is at a temperature around 4.2 K, and it accommodates a magnetic field- measuring rotating coil, NMR probe, and Hall probe within its warm space. Besides preventing the rotating parts of the probe from freezing during the measurement operation, it also reduces the heat leak that reaches the magnet cold mass through the beam tube. Therefore, the warm bore is a special dewar in itself, which works between 4.2 K and about 283 K.

Contrary to a normal dewar, the temperature of the outer wall of the warm bore is 4.2 K, whereas the inner space of the bore is maintained at about 283 K. The thermal insulation vacuum jacket of the bore is very long (19 m in SSC dipole magnet test) and very narrow (only around 2 mm). The thermal insulation assembly in the vacuum space of the warm bore must be specially designed to meet the design requirement of heat leak. A temperature sensor and temperature controller are recommended to monitor and adjust the warm bore heater, resulting in as little heating as possible for maintaining a warm environment. It is desired that the magnetic field measurements be performed at the full magnet operating current

A warm finger about 3.3 m long, with an outer diameter of 40.56 mm, a space of 2.88 mm for filling superinsulation, and an inner diameter of 28.85 mm was designed, tested, and used for a SSC short-dipole cryogenic test.[4] The thermal performance is in good agreement with design specifications. The measured heat leak was 3.2 W. A warm bore for SSC full-size dipole magnet cryogenic test is under design. The schematic cross section of a warm bore design in which the warm bore has a vacuum separate from the cryostat vacuum is shown in Figure 7. This design uses three bellows, two of which compensate for thermal movement during magnet cooldown and warm-up. The other bellow is used for coaxial alignment.

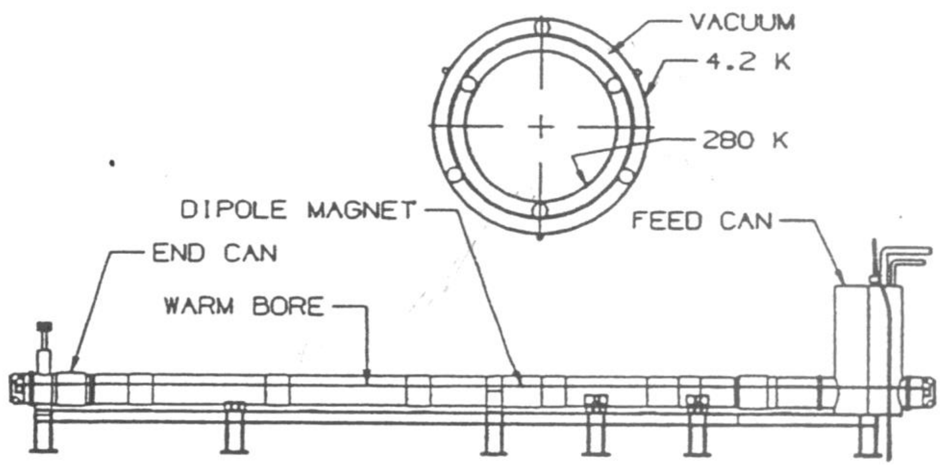

Figure 7. A schematic of a warm bore and its simplified cross section.

One of the most important issues in designing a warm bore is how to further reduce the heat leaks. The heat leak though the warm bore to the beam tube can be calculated by the temperature change, $\triangle T_0$, in the nozzles of the magnet cold mass. The other important fact to know is the temperature change in the annular areas around the superconducting coil, which depends on the following factors: (1) the heat teak though the warm bore to the beam tube, (2) the portion of mass flow rate through the annular area to the total flow rate, and (3) the heat transfer distribution to the He in the annular area, cold mass and the He in the by-pass passages. The temperature increase in the annular region as a function of the heat leak and single-phase He mass flow rate in a SSC dipole magnet has been calcuated. [3]

THE DESIGN OF FEED AND END CANS

In order to provide cryogens to the magnet being tested as well as the cryogenic vacuum and the support of other instrumentation, a magnet test stand system is employed consisting of a feed can, an end can, and a cold test stand. The feed can first feeds the cryogens to the end can by-passing the magnet, then the He turns around into the magnin and cools the magnet to 4.3 K. The used cryogenic He returns to the refrigeration system of MTL. The feed and end cans also provide all the electrical wiring connections and power connections to transfer all of the signal and power to and out of the magnet being tested. The feed and end cans have the necessary mechanical flanges to hold the warm bore in place and to allow a vacuum between it and the beam tube. Both the cans have provisions to create a thermal insulating vacuum in the magnet with thermocouple and cold cathode gauges to read the vacuum. The magnet and the cans are elevated from the ground by the cold test stand, which distributes the magnet load, stabilizing the magnet from quench and vacuum forces, and also aligning the magnet with respect to the cans. Two pairs of feed cans and end cans will be designed and manufactured for MTL by

Fermilab per SSC specifications.

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REFERENCES

[1] "Site Specific Conceptual Design," SSCL, 2550 Beckleymeade Ave., Dallas, Texas (1990).

[2] I. Syromyatnikov and Q. S. Shu, "Feed and end cans instrumentation design and specification," internal doc., Test and Data Management Department, SSCL (1991).

[3] Q. S.Shu, I. Syromaymikov, and A. Zolotov, "MTL planning and instrumentation development for heat leak measurement," Workshop on Testing of SSC Magnet Cryogenic Performance, SSCL, Dallas, Texas, February 11-12, 1992.

[4] Q.S. Shu, J. Demco, I. Syromyatnikov, and A. Zolotov, "Optimum thermal design of the 10 kA vapor cooled power leads for the magnet cryogenic test at the MTL," MD-TA-213, SSC Laboratory (1992).

[5] Q.S. Shu, "Design and Specification of the Warm Finger for Magnet Vertical Cryogenic Test," Test and Data Management Department, SSCL (1991).